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For: PARTICLE DETECTION BY
ELECTRON MULTIPLICATION

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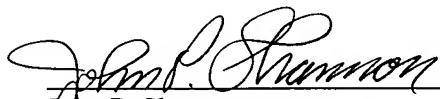
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Sir:

Submitted herewith is a certified copy of Application No. 2003900277 filed on January 20, 2003 in Australia, the priority of which is claimed in the present application under the provisions of 35 U.S.C. 119.

Respectfully submitted,

Date: February 11, 2004



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I, JULIE BILLINGSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2003900277 for a patent by ETP ELECTRON MULTIPLIERS PTY LTD as filed on 20 January 2003.

WITNESS my hand this
Twenty-third day of January 2004

JULIE BILLINGSLEY
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AUSTRALIA

Patents Act 1990

PROVISIONAL SPECIFICATION

Invention Title: **Particle detection by electron multiplication**

The invention is described in the following statement:

PARTICLE DETECTION BY ELECTRON MULTIPLICATION

Field of the Invention

This invention relates generally to the detection of particles and is concerned in particular with enhancements for this purpose of electron multiplier configurations.

In the context of this specification, a "particle" may be an ion or other charged particle, a neutral particle or a photon, that is capable, when having predetermined characteristics, to cause an impacted surface to generate an electron. A common application of electron multipliers, however, is the detection of specific ions, for example in mass spectrometers, and hence for convenience particles to be detected will sometimes be referred to herein as ions.

Background Art

To optimise the performance of an electron multiplier, it is often desirable to have a large sensitive input area so that particles can be detected which are incident over a large area. This requirement often results in a mis-match between the desired sensitive input area and the sensitive area of the amplifying section of the electron multiplier (which can be much smaller). In this case it is desirable to include a focussing element, usually referred to as a focussing lens, between the device's input aperture and its amplifying section.

As well as enabling the detector to have a large sensitive input area, a number of additional requirements for the focussing lens will be necessary if the device is to be used for special applications such as time-of-flight mass spectrometry (TOF-MS). For TOF-MS applications it is critical to accurately measure the arrival time of the ions that are detected over the sensitive input area. To achieve this objective, the focussing lens, at least in a preferred form, should be such as to contribute little or no distortion to the relative measured arrival times of input ions. Expressed another way, if multiple ions arrive at the detector and are spread uniformly over the input area and are all coincident in time, the electrons

(resulting from these ions) exiting the lens should all impact the first dynode of the amplifying section substantially in coincidence.

A focussing lens typically includes an ion impact plate as the first element of the lens assembly. This ion impact plate is an integral component of most ion detectors and has the function of converting the input ions, to be detected, into electrons. The emission of low-energy secondary electrons from the impact plate, typically as a beam of electrons, is the desired response to the plate being struck by sufficiently energetic particles, and forms the principal signal to be amplified by the detector. The incoming signal ions may cause numerous other interactions that may generate particles within the detector. These particles include:

- a) Grid ions: Ions that are emitted from the detector's entry grid as a result of an impact on the grid by a signal ion. They can be positive or negative, low energy or high energy.
- b) Grid electrons: Electrons that are emitted from the detector's entry grid as a result of an impact on the grid by a signal ion.
- c) Grid neutrals: Neutral atoms or molecules that are emitted from the detector's entry grid as a result of an impact on the grid by a signal ion.
- d) Impact plate ions: Secondary ions that are emitted from the detector's impact plate as a result of an impact on the plate by a signal ion. They can be positive or negative, low energy or high energy.
- e) Impact plate neutrals: Neutral atoms or molecules that are emitted from the detector's impact plate as a result of an impact on the plate by a signal ion.

For time-of-flight mass spectrometry all particles resulting from these interactions within the detector (apart from secondary electron emission) generate

unwanted artefact signals in the detector output. Such artefacts are usually seen as unwanted small peaks in the mass spectrum, which are not coincident with the primary signal associated with the incoming ion, and thus add confusion when interpreting the spectrum. It is desirable to eliminate or minimise these artefacts so
5 that they no longer unduly interfere with the intended signal.

In short, a primary objective of the invention is therefore to spatially focus the particles to be detected, sometimes referred to as the signal or signal carrying particles, without loss of timing information.

Summary of the Invention

10 The present invention proposes two mechanisms for achieving the just-mentioned objective that may each be employed alone, in conjunction in the same electron deflection or sequentially. Both mechanisms take advantage of the secondary electrons that result from the impact of energetic electrons against a surface. A surface able to function in this way is hereinafter referred to as a
15 dynode. Both mechanisms involve deflection of electrons by an electrostatic field in conjunction with a magnetic field preferably orthogonal or near orthogonal to the electrostatic field, in contrast to the typical environment of most commercial electron multipliers in which deflection is by electrostatic field only. (See, e.g. the "venetian blind" structures of JP2-291656 and 2-291657). In the combined field
20 arrangements of the present invention, the low energy secondary electrons will preferably follow a near cycloidal trajectory path in such a combination of fields. The distance the electron travels along a surface in this near cycloidal trajectory (and its radius of curvature) will be proportional to the electrostatic field potential (E) divided by the square of the magnetic field potential (B): $x = E/B^2$. Therefore,
25 this E/B^2 ratio is a convenient way of defining the system's operational parameters.

The first mechanism involves deflection of the electrons from one dynode to another in a combined field where the E/B^2 ratio is decreased from the electron emitting dynode to the next target dynode. The second mechanism involves
30 deflection of electrons through an angle greater than 180° in a combined field with

either a uniform or non-uniform E/B^2 ratio. This latter technique has optimal time coherence for deflections at or near 180° , at or near 270° , or at or near 360° (and larger multiples of 90°).

In a first aspect, the invention provides a particle detector employing
5 electron multiplication, including:

cathode means defining an impact surface on which particles impact, which surface has a finite probability of generating at least one electron for each impacting particle having predetermined characteristics;

10 a plurality of electron multiplication dynode segments, including a first dynode segment, arranged in an array; and

respective means for generating electrostatic and magnetic fields in a space extending from said impact surface past said dynode segments, whereby said electrons cascade and multiply
15 successively along said array of dynode segments;

wherein said means for generating said magnetic and electrostatic fields are configured whereby the E/B^2 ratio adjacent any of said dynode segments is smaller than adjacent the preceding dynode segment or impact surface relative to the direction of the cascade,
20 whereby to decrease the radius of curvature of the electron trajectories along said cascade and to thereby focus the electron trajectories in at least two dimensions.

Preferably, the E/B^2 ratio is progressively decreased from the first dynode segment or impact surface to the next dynode. In one embodiment, the decrease
25 is confined to the region from the impact surface to the first dynode segment. In another embodiment, there is alternatively or additionally a progressive decrease in the E/B^2 ratio along the dynode array.

In its first aspect, the invention also provides electron focussing apparatus including:

5 cathode means defining an impact surface on which particles impact, which surface has a finite probability of generating at least one electron for each impacting particle having predetermined characteristics;

a dynode segment; and

respective means for generating electrostatic and magnetic fields in a space extending from said impact surface to said dynode segment;

10 wherein said means for generating said electrostatic and magnetic fields are configured whereby the E/B^2 ratio adjacent said dynode segment is smaller than adjacent the impact surface, whereby to decrease the radius of curvature of the electron trajectories adjacent the first dynode relative to adjacent the impact surface and to
15 thereby focus the electron trajectories in at least two dimensions.

Preferably, the E/B^2 ratio is progressively decreased from the impact surface to the first dynode.

Preferably, said magnetic field is configured to also focus the electron trajectories in a direction orthogonal to the direction of said cascade.

20 In a second aspect, the invention provides a particle detector employing electron multiplication, including:

25 cathode means defining an impact surface on which particles impact, which surface has a finite probability of generating at least one electron for each impacting particle having predetermined characteristics;

a plurality of electron multiplication dynode segments, including a first dynode segment, arranged in an array; and

5 respective means for generating electrostatic and magnetic fields in a space extending from said impact surface past said dynode segments, whereby said electrons cascade and multiply successively along said array of dynode segments;

10 wherein said first dynode segment is positioned and said means for generating said electrostatic and magnetic fields are configured to cause said electrons to deflect on average through greater than 180° before impacting the first dynode segment, whereby to focus, in at least two dimensions, multiple electrons generated from any given area of said impact surface to a smaller area at said first dynode segment.

15 Preferably, for optimal time coherence, the average deflection is through substantially or approximately a multiple of 90° . In an especially convenient configuration, the average deflection is through substantially 270° .

20 Preferably, said dynode array is substantially coplanar. In the case of 270° deflection, the result is that the direction of particle incidence on the impact surface is substantially parallel to the plane of the dynode array, an especially convenient configuration.

The dynodes may be discrete or segments of a continuous dynode formed, for example, from resistive secondary electron emissive material.

In its second aspect, the invention further provides electron focussing apparatus including:

25 cathode means defining an impact surface on which particles impact, which surface has a finite probability of generating at least one electron for each impacting particle having predetermined

characteristics; and

a dynode segment;

respective means for generating electrostatic and magnetic fields in a space extending from said impact surface to said dynode segment;

5 wherein said dynode segment is positioned and said means for generating said electrostatic and magnetic fields are configured to cause said electrons to deflect on average through greater than 180° before impacting the dynode segment, whereby to focus, in at least two dimensions, multiple electrons generated from any given area of
10 said impact surface to a smaller area at said dynode segment.

Preferably, for optimal time coherence, the deflection is through substantially or approximately a multiple of 90° . In an especially convenient configuration, the deflection is through substantially 270° .

In a third aspect, the invention provides a particle detector employing
15 electron multiplication, including:

cathode means defining an impact surface on which particles impact, which surface has a finite probability of generating at least one electron for each impacting particle having predetermined characteristics;

20 a plurality of electron multiplication dynode segments, including a first dynode segment, arranged in an array; and

respective means for generating electrostatic and magnetic fields in a space extending from said impact surface past said dynode segments, whereby said electrons cascade and multiply
25 successively along said array of dynode segments;

5 wherein said means for generating a magnetic field comprises at least two magnetic poles positioned with respect to said cathode means to generate a magnetic field extending in a direction generating orthogonal or near orthogonal to said electrostatic field and configured to cause focussing, in said direction, of trajectories of said impacting particles and/or of trajectories of said electrons from said impact surface to said first dynode segment.

In the third aspect, the invention also provides electron focussing apparatus including:

10 cathode means defining an impact surface on which particles impact, which surface has a finite probability of generating at least one electron for each impacting particle having predetermined characteristics; and

a dynode segment;

15 respective means for generating electrostatic and magnetic fields in a space extending from said impact surface to said dynode segment;

20 wherein said means for generating a magnetic field comprises at least two magnetic poles positioned with respect to said cathode means to generate a magnetic field extending in a direction generating orthogonal or near orthogonal to said electrostatic field and configured to cause focussing, in said direction, of trajectories of said impacting particles and/or of trajectories of said electrons from said impact surface to said dynode segment.

25 The invention further extends to an electron focussing apparatus or a particle detector incorporating two or three of the three aspects of the invention. A preferred form of such apparatus or detector has all three aspects of the invention controlling the electron trajectories from the impact surface to the first dynode.

The invention also extends to an electron multiplier comprising a particle detector according to one or more of the first, second and third aspects of the invention.

In each aspect of the invention, the impact surface may itself be a dynode
5 for generating electrons in response to impacting electrons. Typically, the impact surface is associated with an entrance grid.

Brief description of the drawings

A preferred embodiment of the invention will now be described, by way of example only, with reference to the accompanying diagrams, in which:

10 Figure 1 is a cross-sectional schematic representation of a focussing configuration for an electron multiplier, which configuration incorporates simultaneous and sequential co-operating application of the three aspects of the invention to focussing of the secondary electron trajectories; and

15 Figure 2 is a cross-section on the line 2-2 in Figure 1, extended at its lower end and depicting the field lines for the magnetic field generated by the depicted pole configuration.

Embodiments of the Invention

The illustrated electron multiplier 10 includes cathode means in the form of a relatively large ion impact plate 12 constituting an input dynode, designated
20 dynode 1. Dynode 1 is disposed inwardly of an entrance grid 14 defining an input aperture. Typical input ion trajectories are indicated at 16.

A co-planar or linear array 20 of dynodes 22 extends at 90° to impact plate 12 in a direction behind and away from plate relative to entrance grid 14. The plane of dynode array 20 lies slightly laterally of the adjacent edge 13 of plate 12.
25 Dynodes 22 are designated dynodes 2, 3, 4 and 5 and are successively smaller in functional surface area and in spacing from the preceding dynode. Dynode 5 is

the output dynode of the focussing configuration and marks the start of the amplifying section 24 (Figure 2).

A rectangular plate 30 is disposed as shown as an electrode for shaping an electrostatic field between it and dynodes 1 and 2, while a pair of opposed mirror-image magnetic pole configurations 50,52 (Figure 2) are provided to generate a magnetic field 40 substantially or nearly orthogonal to the electrostatic field in a direction (the z-axis direction) into the page. Plate 30, together with pole configurations 50,52 and dynodes 1 and 2, define a chamber 32 in which secondary electrons generated by plate 12 are guided along trajectories 35 to dynode 2 by the combined effect of the electrostatic field and magnetic field 40. ~~Trajectories 35 are near cycloidal.~~ Progressively more positive voltages are applied between the successive dynodes 1 to 5 to ensure that electrons passing from one dynode to the next have sufficient energy to generate secondary electrons on impact. Voltages must be applied to the entrance grid 14 and field shaping electrode 30 that are more positive than the dynode 1 voltage so that they attract electrons emitted from dynode 1. The E/B^2 ratio is continually decreased from the top to the bottom of the diagram, in this case by increasing the strength of magnetic field 40. This is effective, as shown by the illustrated trajectories, to progressively focus the trajectories in at least the two dimensions (the x and y dimensions) parallel to the page in the diagram of Figure 1. Instead of increasing the magnetic field strength (B), B may be held substantially constant while the electrostatic field is reduced, or a suitable balance may be obtained that progressively reduces the E/B^2 ratio from dynode 1 or 2 to dynode 5, but achieves optimum voltages at the various electrodes for optimum overall performance.

Field shaping plate 30 is extended by an attractor plate 36 that lies spaced from dynodes 2 to 5, but is inclined so as to converge downwardly towards the plane of the dynode array 20.

Ions enter through a uniform electrostatic field generated between the ion impact surface (dynode 1) and parallel entrance grid 14. Secondary electrons (generated from the ion impact) are deflected along trajectories 35 by the combined effect of the electrostatic and magnetic fields through an average angle

of approximately 270° to dynode 2. This is effective to focus the electrons generated from any given area of impact plate 12 (dynode 1) to a smaller area at dynode 2. In some configurations the impact plate 12 may need its end to be bent up (not shown in diagram) at its right hand end (as seen in the diagram) to
5 maintain a near uniform electrostatic field over the ion input portion. This is to minimise time distortion of input ions traversing between the entrance grid and the ion impact plate.

In this example, the E/B^2 ratio in the dynode 1 area is $\sim 10^9$ volts/meter-tesla² and the E/B^2 ratio is decreased by ~ 20 times from the top to the
10 bottom of the structure as shown in the diagram. Both of these are practical values. The first stage of focussing from dynode 1 to dynode 2 will reduce the beam size to between 20% and 25% of the input beam size. The overall beam reduction for the entire lens assembly (dynode 1 to dynode 5) will be $>20:1$. Analysis has shown that with the appropriate choice of design parameters this
15 structure will contribute less than 300 picoseconds of distortion between the arrival time of coincident ions striking the impact plate and the arrival of electrons at the output dynode of the lens assembly.

Figure 2 provides the detail of the magnetic pole configuration in which magnetic contour lines 41 indicate contours of equal magnetic field strength.
20 Primary plates 54, 55 control the magnetic field shape in the dynode 1 area and extend from upper edges 54a, 55a generally aligned with entrance grid 14 to bottom edges generally aligned with dynode 5. Dynode 1 extends between plates 54, 55, while dynodes 2, 3, 4 and 5 are of substantially smaller lateral extent but are centrally located between plates 54, 55. Enhancement of intensity below this
25 region is achieved by upstanding pole pieces 58,59 immediately below the facing aligned bottom edges of ledges 54,55.

Thus far in the discussion, reference has been made to focussing of the electron trajectories in the x and y directions, i.e. the dimensions parallel to the page in Figure 1. Focussing in the z direction is also obtained by the magnetic
30 pole and field configuration depicted in Figure 2. Firstly, the increasing field strength from dynode 2 to dynode 5 and the field shape achieved by pole pairs

54,55 and 58,59 combine to centralise or focus the "beam" of electron trajectories 35 in the z direction. Secondly, the positioning of the upper edges 54a,55a of pole plates 54,55 at the level of entrance grid 14 is found to generate an advantageous edge effect that focuses, in the z direction, the electron trajectories 35 between 5 impact plate 12 and dynode 2. These edge effects cause a curvature of the magnetic field as seen by the magnetic field strength contours 41 (Figure 2) which deflect the electrons towards the center of the structure in the z direction.

Because the lens assembly utilises magnetic fields in the electron deflection process all other particles will be excluded. Magnetic deflection is mass 10 sensitive and as a result ions and neutrals will experience very little or no deflection in a magnetic field designed for electrons. The only particles that will reach dynode 2 in this device are low energy electrons that originate at the impact plate surface. Therefore the lens assembly will generate minimal artefact signals in TOF-MS applications.

15 In the described implementation and diagram, dynodes 2 to 5 are shown as separate electrodes: each is a conductive surface with a different applied voltage. As an alternative these separate dynodes could be replaced by a single resistive dynode. In such an implementation the resistive dynode would consist of an electrically resistive surface where a voltage is applied between two opposite ends 20 so that the voltage measured on the surface varies continually from one end to the other. The surface must also have sufficient secondary electron yield so that incident electrons generate enough secondary electrons to sustain the process through each of the required stages (electron impact followed by secondary electron emission). The inherent secondary electron emission of the surface 25 material may be suitable for this process, or the surface may need to be coated with a more suitable material. As a practical matter the secondary electron yield at each impact should be greater than 1, but the device would still function with smaller secondary electron yield.

Secondary electron yield of any material is almost always a strong function 30 of the electron impact energy, which in turn is derived from the voltage difference between the electron emission surface and the electron impact surface. Thus, the

voltage applied between the two ends of the resistive dynode must be great enough so that there is sufficient voltage between electron emission and impact positions to generate secondary electrons. The distance between emission and impact positions will be determined by the combined electrostatic and magnetic field strengths.

It will be understood that both methods are used in the transition from dynode 1 to dynode 2. The focussing that occurs in the electron transitions from dynode 2 to 3, 3 to 4, and 4 to the output dynode 5 are examples of the first aspect of the invention.

10 It will be understood that the invention disclosed and defined in this specification extends to all alternative combinations of two or more of the individual features mentioned or evident from the text or drawings. All of these different combinations constitute various alternative aspects of the invention.

15

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20 January 2003

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